OROVILLE FERC RELICENSING
(PROJECT NO. 2100)

INTERIM REPORT
SP-F10, Task 1C

EVALUATION OF FLOW-RELATED PHYSICAL IMPEDIMENTS IN THE FEATHER RIVER BELOW THE FISH BARRIER DAM

REVIEW DRAFT

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1.0 SUMMARY

This deliverable evaluates the potential for flow-related physical passage impediments to adult salmonid immigration in the Feather River below the Fish Barrier Dam, as defined in study plan SP-F10. Various statistical analyses were conducted in order to identify any consistent temporal pattern among flow and escapement that might be suggestive of potential flow-related physical impediments to upstream passage. A linear regression approach was utilized to evaluate potential relationships between the total Chinook salmon escapement estimate and various flow rate variables based on a defined regulatory or flow level thresholds. In addition, an ANOVA approach compared two series of adult Chinook salmon escapement estimates, which were separated and grouped based on a defined regulatory or flow level threshold. The statistical examinations indicate that no statistically significant difference exists between adult Chinook salmon spawning escapement in dryer, lower flow years compared to wetter, higher flow years. Flow-related physical passage impediments to adult salmonid upstream migration are not apparent in the Feather River.

2.0 PURPOSE

The purpose of Task 1C of SP-F10 is to evaluate potential relationships between flow and flow-related physical passage impediments to adult salmonid immigration in the Feather River. Anadromous salmonids which utilize the Feather River as a migration corridor include steelhead (*Oncorhynchus mykiss*) and Chinook salmon (*Oncorhyncus tshawytscha*). On March 19, 1998, naturally spawned Central Valley steelhead (*O. mykiss*) were listed as threatened under the federal Endangered Species Act (ESA) by the National Marine Fisheries Service (NMFS) (NMFS 1998). The Central Valley steelhead Evolutionarily Significant Unit (ESU) includes all naturally-spawned populations of steelhead (and their progeny) in the Sacramento and San Joaquin rivers and their tributaries, which includes naturally-spawned steelhead in the Feather River (NMFS 1998).

On September 19, 1999, naturally-spawned Central Valley spring-run Chinook salmon (*O. tshawytscha*) were listed as threatened under the federal ESA by NMFS (NMFS 1999). The Central Valley spring-run Chinook salmon ESU includes all naturally-spawned populations of spring-run Chinook salmon in the Sacramento River and its tributaries, which includes naturally-spawned spring-run Chinook salmon in the Feather River (NMFS 1999). In the same ruling, NMFS determined that naturally-spawned Central Valley fall-run Chinook salmon (*O. tshawytscha*) were not warranted for listing under the federal ESA (NMFS 1999). However, the Central Valley fall-run Chinook salmon ESU was designated as a candidate for listing (NMFS 1999). The Central Valley fall-run Chinook salmon ESU includes all naturally-spawned populations of fall-run Chinook salmon in the Sacramento and San Joaquin rivers and their tributaries, which includes naturally-spawned fall-run Chinook salmon in the Feather River (NMFS 1999).

In order to evaluate the potential relationships between project operations and ESA-listed spring-run Chinook salmon and steelhead, as well as candidate fall-run Chinook salmon, it is desirable to evaluate the potential for flow-related physical passage impediments to adult salmonid immigration in the Feather River.

In addition to the ESA, Section 4.51(f)(3) of 18 CFR requires reporting of certain types of information in the Federal Energy Regulatory Commission (FERC) application for license of major hydropower projects, including a discussion of the fish, wildlife, and botanical resources in the vicinity of the project (Code of Federal Regulations 2001). The discussion is required to identify the potential impacts of the project on these resources, including a description of any anticipated continuing impact from on-going and future operations. As a subtask of Study Plan (SP) F-10, *Evaluation of Project Effects on Salmonids and their Habitat in the Feather River Below the Fish Barrier Dam*, Task 1C fulfills a portion of the FERC application requirements by evaluating the potential for flow-related physical passage impediments to adult salmonid immigration in the Feather River below the Fish Barrier Dam.

Ongoing operation of the Oroville Facilities influences flows and water temperatures in the Feather River downstream of the Fish Barrier Dam. Water temperatures and flow are both important factors influencing the ability of adult salmonids to migrate upstream. Task 1 of SP-F10 will evaluate the effects of Feather River water temperatures and flow on immigrating adult salmonids in the Feather River. Tasks 1B, 1D, and 1E will evaluate the effects of water temperatures on adult salmonids. Task 1B will evaluate the effect of water temperatures on attraction of migrating salmonid adults, while Tasks 1D will evaluate the effects of water temperatures on pre-spawning adult salmonids and subsequent reproduction. Task 1E will evaluate the effects of water temperatures on early upstream migrating adult Chinook salmon holding habitat and use patterns. Tasks 1A and 1C will evaluate flow-related effects on immigrating adult salmonids. Task 1A evaluates the effects of Feather River flows on attraction of migrating salmonids and Task 1C, herein, evaluates the effects of flow on potential physical passage impediments to adult salmonid immigration. For further description of Tasks 1A, 1B, 1D, or 1E relating to adult salmonid immigration, see SP-F10 and associated interim and final reports.

Adequate flows are necessary to allow fish passage past potential physical impediments to upstream migration. The flow regime associated with the ongoing operation of the Oroville Facilities has the potential to impede the passage of salmonids migrating to upstream spawning areas in the Feather River. Task 1C of SP-F10 is specifically designed to evaluate potential relationships between flow and flow-related physical passage impediments to adult salmonid immigration in the Feather River (DWR 2002a). In order to assess whether the flow regime associated with the current operations of the Oroville Facilities results in flow-related physical passage impediments to adult salmonid immigration in the Feather River, historical flow records were collected and compared to adult escapement estimates. Although this approach is not a traditional "critical riffle" approach, as explained below under the "Background" section of this report, it was the approach deemed most appropriate by the Oroville Facilities Relicensing Environmental Workgroup for assessing flow-related physical passage impediments given the history of adult salmonid spawners returning to the Feather River spawning grounds (DWR 2002a). The data analysis conducted to satisfy this portion of Task 1 of SP-F10 was designed to identify any consistent temporal pattern among low flow and low escapement years that might be suggestive of potential flow-related physical impediments to upstream passage, and that might justify a detailed study on critical riffles and passage criteria.

Various statistical analyses were conducted in order to identify any consistent temporal pattern among low flow and low escapement years that might be suggestive of potential flow-related physical impediments to upstream passage. As described in detail below under the "Methodology" section of this report, these analyses consisted of comparing flow and escapement data using linear regression and ANOVA approaches. The conclusions drawn from this data analysis may be used as the basis for suggesting potential protection, mitigation, and enhancement measures (PM&Es) designed to reduce flow-related physical impediments to upstream passage of adult salmonids in the Feather River.

3.0 BACKGROUND

The upstream extent of the study area for this evaluation is the Fish Barrier Dam and the downstream extent of the study area is the confluence of the Feather and Sacramento rivers. This geographic range within the Feather River encompasses the area used as a migration corridor by adult steelhead, spring-run Chinook salmon, and fall-run Chinook salmon on their way to spawning areas on the Feather River. The reach of the Feather River extending from the Fish Barrier Dam to the Sacramento River is composed of two operationally distinct segments. The upstream segment extends from the Fish Barrier Dam at river mile (RM) 67.25 to the Thermalito Afterbay Outlet (RM 59), while the downstream segment extends from the Thermalito Afterbay Outlet (RM 59) to the confluence of the Feather and Sacramento Rivers (RM 0). The flow regime associated with each of these segments is distinct and is summarized below.

Minimum flows in the lower Feather River were established in the August 1983 agreement between the California Department of Water Resources (DWR) and the California Department of Fish and Game (DFG) (DWR 1983). The agreement specifies that DWR release a minimum of 600 cubic feet per second (cfs) into the Feather River from the Thermalito Diversion Dam for fisheries purposes. Therefore, the reach of the Feather River extending from the Fish Barrier Dam to the Thermalito Afterbay Outlet is operated at 600 cfs all year, with variations in flow occurring rarely, only during flood control releases or in the summer in order to meet downstream temperature requirements for salmonids.

For a Lake Oroville surface elevation greater than 733 feet, the minimum in-stream flow requirements on the Feather River below the Thermalito Afterbay Outlet are provided in **Table 1** as follows (DWR 1983):

Table 1. Minimum in-stream flow requirements on the Feather River.

Percent of normal[1] runoff (%)	Oct.-Feb. (cfs)	Mar. (cfs)	Apr.-Sep. (cfs)
> 55	1,700	1,700	1,000
< 55	1,200	1,000	1,000

[1] Normal runoff is defined as 1,942,000 acre-feet, which is the mean (1911 – 1960) April through July unimpaired runoff near Oroville.

Unlike the constant flow regime in the upstream segment of the Feather River, the flow regime in the reach of the Feather River extending from the Thermalito Afterbay Outlet (RM 59) to the confluence of the Feather and Sacramento rivers (RM 0) varies depending on runoff and month. Although the minimum flow requirements are described above, flow in the reach of the Feather

River extending from the Thermalito Afterbay Outlet to the confluence of the Feather and Sacramento rivers typically varies from the minimum flow requirement to 7,500 cfs (DWR 1982). Flow in this reach is, therefore, more highly varied than flow in the upstream segment. Flow in the downstream segment is additionally influenced by small flow contributions from Honcut Creek and the Bear River, and by larger flow contributions from the Yuba River (**Figure 1**). Shanghai Bench, a clay riffle located between RM 26 and RM 25 in the downstream segment, has been identified as the most likely possible physical, flow-related impediment to upstream migration in the Feather River (DWR 2002a).

Estimates of adult Chinook salmon escapement in the Feather River are split into two components: adult Chinook salmon entering the Feather River Fish Hatchery; and in-channel adult Chinook salmon spawners. From 1967 (when formal operation of the hatchery began) onward, records of annual adult Chinook salmon escapement at the Feather River Fish Hatchery are available, and are expressed as total counts of individual adult salmon climbing the fish ladder and entering the hatchery each spawning year. The hatchery gates are typically opened in September. Adult Chinook salmon returning to the hatchery during September are considered spring-run Chinook salmon, while those returning during October and November are considered fall-run Chinook salmon (DWR 2002b).

The number of adult Chinook salmon spawning in the Feather River has been estimated since 1955 using several techniques. Beginning in 1955, DFG conducted carcass surveys in the Feather River from October through December to provide annual abundance estimates of adult Chinook salmon spawning escapement. Because Chinook salmon die after spawning, counting carcasses is a viable technique for assessing the number of adult spawners that have returned to spawn in the Feather River. From 1953 through 1978, annual estimates of fall-run in-channel spawners were determined by direct counts expanded relative to data from past years, or expanded by the percentage of the total population direct count was thought to represent. These techniques are highly subjective, with yearly changes in spawning distribution (spatial or temporal) and surveyor experience influencing the accuracy of the estimates (DWR 2002b).

From 1955 through 1981, spring-run in-channel spawners were estimated by direct counts like those used to estimate fall-run in-river spawners. When the fish hatchery began operations in 1967, spring-run were also counted based on the numbers of salmon entering the hatchery during the month of September. Therefore, estimates of adult spring-run escapement between 1967 and 1981 are a sum of in-channel and hatchery estimates. After 1981, DFG ceased to estimate spring-run Chinook salmon in-channel spawning because spatial and temporal overlap with fall-run Chinook salmon spawners made it difficult to distinguish between the two races. Spring-run estimates after 1981 are based solely on salmon entering the hatchery during the month of September (DWR 2002b).

In 1979, DFG began to employ mark-recapture techniques to estimate adult in-channel spawning escapement, in which spawned-out salmon carcasses are recovered, tagged, and placed back in the stream. Stream surveys were conducted weekly and the proportion of tagged carcasses recovered was used to estimate sampling efficiency. Total abundance was then projected by expanding the number of carcasses checked for tags by the sampling efficiency. This expansion was accomplished by applying one of several mark-recapture statistical models, with the Schaefer model being most popular. The mark-recapture method was applied in every year after

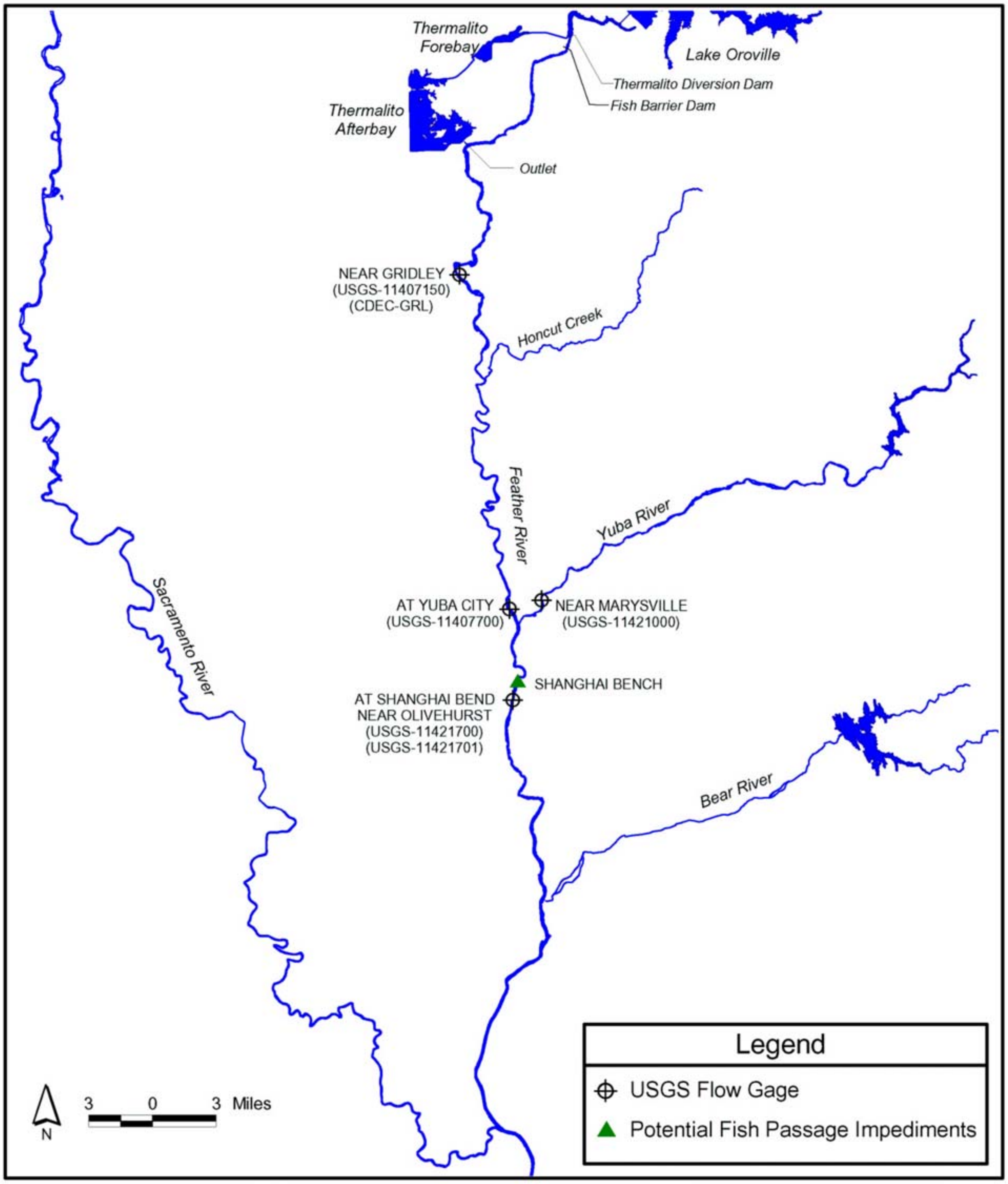

Figure 1. Potential fish passage impediments.

1979, except for 1988, 1990, and 1998. In these years, an expanded index count was applied, similar to those used prior to 1979. The precise sampling strategy (study design) and level of effort utilized in each year's mark-recapture survey is poorly detailed in the DFG annual reports. However, discussions with DFG biologists indicate that the surveys were conducted weekly, two days each week, utilizing one boat, and staffed by two to four crew persons. The survey was divided into two distinct river reaches; Fish Barrier Dam to Thermalito Afterbay Outlet and Thermalito Afterbay Outlet to Gridley Bridge. Usually one day was spent on each of these river sections and overall the typical survey area covered approximately 16 river miles (DWR 2002b).

Beginning in 2000, with completion of an intensive escapement survey on the Feather River, DWR and DFG have cooperatively conducted carcass surveys and estimated annual adult Chinook salmon spawning escapement. The 2000 survey was based on the same basic premise of earlier carcass surveys and mark-recapture techniques utilized on the Feather River since 1979; however, the 2000 study increased the level of effort, followed a more rigorous set of sampling protocols, and collected information on a finer spatial scale. The survey area consisted of two eight-mile river segments, the reach of the Feather River extending from the Fish Barrier Dam to the Thermalito Afterbay Outlet and the reach of the Feather River extending from the Thermalito Afterbay Outlet to the confluence with Honcut Creek. These two river segments were further divided into several sections, and the reach of the Feather River extending from the Fish Barrier Dam to the Thermalito Afterbay Outlet was further divided into units consisting or a single riffle/pool sequence. In 2000, mark-recapture experiments on salmon carcasses were conducted weekly from September 5 through December 15. Population estimates were generated using the Schaefer mark-recapture model. Detailed collection of mark-recovery data in the reach of the Feather River extending from the Fish Barrier Dam to the Thermalito Afterbay Outlet allowed population estimates to be made for individual units (representing a single riffle/pool sequence) or grouped over an entire river segment. This analytical flexibility made it possible to perform a "bootstrap" re-sampling exercise, in which different sampling strategies and levels of sampling effort could be evaluated for their effect on the overall population estimate for the reach of the Feather River extending from the Fish Barrier Dam to the Thermalito Afterbay Outlet (DWR 2002b).

The year 2001 estimate of annual adult Chinook salmon spawning escapement in the Feather River was complete similarly to the year 2000 survey discussed above. The year 2000 and 2001 spawning escapement surveys estimated total in-channel Chinook salmon spawning populations of 123,400 and 169,088, respectively, which are by far the highest escapement estimates ever reported on the Feather River (pers. com., B. Cavallo, 2002). Since the 2000 and 2001 surveys employed greater effort and a detailed sampling protocol, it is difficult to compare these estimates to previous estimates, where effort and sampling protocols were poorly documented (DWR 2002b).

The enumeration program for adult steelhead is less extensive than the enumeration program for adult Chinook salmon spawners. As with Chinook salmon, steelhead escapement in the Feather River can be split into two components: adult steelhead entering the Feather River Fish Hatchery and in-channel adult steelhead spawners. Beginning in 1967, when formal operation of the hatchery began, the number of adult steelhead spawners arriving at the Feather River Fish Hatchery was recorded and are expressed as total counts of individual adult steelhead climbing the fish ladder and entering the hatchery each year to spawn. Unlike the estimates available for in-channel Chinook salmon spawners, little specific information is available regarding the location, timing, or magnitude of steelhead spawning in the Feather River (DWR et al. 2002). There are several reasons that no quantitative estimates are available for the number of adult steelhead spawners in the Feather River. One reason is that carcass surveys, which are a reliable method for estimating adult Chinook salmon spawning escapement, are not applicable to steelhead because many do not expire after spawning and most others do not die on the spawning grounds (McEwan 2001). In addition, little is known about steelhead spawning because steelhead redds are generally indistinguishable from Chinook salmon redds in the Feather River due to the superimposition resulting from heavy utilization of spawning riffles by both Chinook salmon and steelhead, and because water clarity is generally poor during the winter months when steelhead spawning occurs, making observation difficult (DWR et al. 2002).

Despite the lack of quantitative numerical estimates of the number of adult steelhead spawners, available information regarding young-of-year (YOY) steelhead distribution and adult steelhead spawner surveys currently underway for the Oroville Facilities Relicensing process may provide some insight regarding steelhead spawning locations. For example, information regarding the distribution of spawning steelhead in the Feather River can be inferred from observations collected during the snorkel surveys performed by DWR from March through August in 1999, 2000 and 2001. From 1999 to 2001, almost all of the steelhead spawning activity appears to have been concentrated between the Fish Barrier Dam and the Thermalito Afterbay Outlet, because 91 percent, 77 percent, and 84 percent of all the YOY (i.e., juveniles with fork lengths smaller than 100 mm) steelhead observations during the snorkel surveys of 1999, 2000 and 2001, occurred a mile downstream of the Fish Barrier Dam, and only one percent of the YOY were observed downstream of the Thermalito Afterbay Outlet (DWR 2002a; DWR 2002b). In addition to snorkel observations of YOY steelhead, three surveys targeted to provide additional information regarding in-channel adult steelhead spawning for the Oroville Facilities relicensing process are detailed in Task 2B of SP-F10 (DWR 2002a). These surveys include an adult steelhead abundance boat survey, an extended snorkel survey to include the months of steelhead spawning, and a steelhead redd survey. Detailed descriptions of these surveys can be found in Task 2B of SP-F10 (DWR 2002a).

As described above, relatively little is known regarding steelhead spawning in the Feather River in comparison to Chinook salmon spawning. Steelhead are present in the Feather River from September through April, with peak immigration probably occurring during September through January (DWR et al. 2002). Most steelhead are thought to spawn in the hatchery, although some spawn in the Feather River (DWR et al. 2002). Because of the lack of numerical estimation of the number of steelhead spawning in the Feather River, it is not possible to assess the proportion of the population which spawns in the Feather River Fish Hatchery. Observations suggest that in-channel steelhead spawning activity probably peaks during November through February, and occurs primarily at the upstream portion of the reach extending from the Fish Barrier Dam to the Thermalito Afterbay Outlet (DWR 2002b). As compared to Chinook salmon, steelhead migrate upstream during periods of higher flows, have superior leaping ability, and the ability to pass through shallower water (DWR et al. 2002).

Traditionally, flow-related physical passage impediments to upstream adult salmonid migration are shallow riffles without sufficient flow to allow for passage of adult salmonids. Such a "critical riffle" is defined as a riffle that has the highest probability of becoming a hindrance to salmonid passage with low river flows. Because of the large number of salmon returning to the upstream-most section of the Feather River (as measured by adult spawner escapement estimates), flow-related physical impediments to adult upstream passage are not generally considered to occur under current project operations (DWR 2002a). The available series of annual adult Chinook salmon in-channel escapement abundance estimates and Chinook salmon returns to the Feather River Fish Hatchery indicate that flow in the Feather River below the Thermalito Afterbay Outlet has never been so low as to block upstream migration passage seriously enough to preclude annual escapement of adult Chinook salmon to the Feather River spawning grounds and the Feather River Fish Hatchery. Since records of adult salmonid returns have been kept, adult Chinook salmon and steelhead have consistently managed to reach the Feather River Fish Hatchery and spawning grounds. Additionally, in their 2001 Biological Opinion, NMFS states *"…Due to the low number of steelhead spawning outside of the Feather River Hatchery, flows of 600 cfs in the low flow channel are expected to generally provide adequate depths and velocities for upstream passage of migrating adults…"* (NMFS 2001). Potential flow-related physical impediments to upstream passage could be expressed in a less dramatic outcome than "low flow equals zero escapement." However, it is anticipated that sufficient water depth is provided under current project operations such that the riffles do not inhibit passage based on insufficient water depth (DWR 2002a).

Although not a typical critical riffle approach, the study approach for completion of Task 1C is the evaluation of the relationship between flows and passage as measured by escapement (DWR 2002a). This approach was deemed most appropriate by the Oroville Facilities Relicensing Environmental Workgroup for assessing flow-related physical passage impediments given the history of adult salmonid spawners returning to the Feather River spawning grounds (DWR 2002a). The data analysis described below under the "Methodology" section of this report was designed to identify any consistent temporal pattern among low flow and low escapement years that might be suggestive of potential flow-related physical impediments to upstream passage. If such consistent temporal patterns are identified through this analysis, a detailed critical riffle evaluation or an evaluation of the relationships between flow and the passage of adult salmonid upstream of Shanghai Bench may be recommended as appropriate.

When evaluating the relationship between flow and adult salmonid escapement, several factors in addition to flow-related physical impediments to upstream passage may influence the relationship between flow and escapement. Both flow and water temperatures are important factors influencing the ability of adult salmonids to migrate upstream and influencing pre-spawning adult salmonids. For example, during upstream migration, adults require sufficient streamflow to provide olfactory and other orientation cues used to locate their natal streams (DWR et al. 2002). If flow is too low to provide adequate attraction for salmonids, escapement could be reduced. However, decreased flows during the immigration period may result in decreased attraction of salmonids to the Feather River, resulting in lower total escapement estimates. This could be the case even if every immigrant adult salmonid that entered the Feather River was able to navigate successfully to the Feather River spawning grounds. Additionally, flow may or may not influence water temperature in the Feather River. If flow is low, water temperatures may increase relative to water temperatures that would occur under the same climatic conditions if higher flow had occurred. Increased water temperatures may impede salmonid immigration (DWR et al. 2002). Therefore, a correlation between low flow and low escapement may be the result of low flow causing increased temperatures, and may not be the result of flow-related physical impediments to upstream passage. Therefore the annual adult salmonid escapement estimates have the potential to be influenced by a variety of other factors in addition to flow-related physical passage impediments. As discussed above under the "Purpose" section of this report, other tasks contained within SP-F10 will analyze the relationship between these other factors (i.e., attraction flows and temperatures) and the immigration, holding, and subsequent reproduction of adult salmonids.

4.0 METHODOLOGY

Task 1C of SP-F10 is specifically designed to evaluate potential relationships between flow and flow-related physical passage impediments to adult salmonid immigration in the Feather River (DWR 2002a). The SP-F10, Task 1C work plan (DWR 2002a) originally specified that "*...the series of annual Chinook escapement abundance estimates and adult steelhead returns to the Feather River Hatchery, and the series of Feather River flows downstream of the Thermalito Afterbay outlet will be compared to identify any consistent temporal pattern among low flow and low escapement years that might be suggestive of potential flow-related physical impediments to upstream passage.*" In order to achieve this objective, the comparative analysis detailed in the work plan required that an ANOVA approach be used to evaluate whether the mean in-channel adult escapement abundance estimates and hatchery counts occurring when the monthly average, median or minimum flows during the months of upstream adult migration were lower than 1,700 cfs was significantly lower than the mean in-channel adult escapement abundance estimates and hatchery counts occurring when the monthly average, median or minimum flows during the months of upstream adult migration were higher or equal to 1,700 cfs (DWR 2002a). The study plan additionally required that a linear regression approach be used to detect whether there was a strong and significant relationship between the adult escapement estimates and the number of days when daily flows during the months of upstream adult migration were lower than 1,700 cfs.

The Study Plan for Task 1C originally included an analysis of flow-related physical impediments to upstream passage for all months of the upstream migration period for fall-run Chinook salmon and spring-run Chinook salmon (March through November) and for all months of the upstream migration period for steelhead (November through April). However, after reviewing flow records and available escapement data, the analysis of potential flow-related physical impediments associated with salmonid immigration was conducted for low flow periods (August through December) utilizing adult Chinook salmon escapement estimates. The following factors contributed to the relatively minor change in specific data sets or estimators used to accomplish Task 1C:

- Flow Period. Historical Feather River flow records below the Thermalito Afterbay Outlet obtained from the USGS surface-water data portal (*http://waterdata.usgs.gov/nwis/discharge*) indicate that monthly mean streamflows near Gridley (1964-1998) are lowest from August through November. In addition, upstream migration of fall-run Chinook salmon and steelhead occurs during the month of December. Therefore, the analysis period was limited to August through December. Monthly mean streamflows during other months of the year and at other locations on the Feather River (i.e., below/at Shanghai Bend) are generally higher due to annual spring run-off and flow contributions from Honcut Creek, the Bear River, and the Yuba River.

- Spring-run Chinook salmon and Fall-run Chinook salmon Escapement Estimates. As discussed above under the "Background" section of this report, estimates of in-channel adult Chinook salmon spawner escapement are limited to carcass surveys conducted yearly from 1955 through 1999 from October through December. Starting in 2000, carcass surveys were also completed during the month of September. Hatchery counts are completed annually from September through March. After 1981, DFG ceased to estimate in-channel spawning spring-run Chinook salmon because spatial and temporal overlap with fall-run Chinook salmon spawners made it difficult to distinguish between the two races. Therefore, no in-channel escapement estimates are available for spring-run Chinook salmon after 1981. Spring-run Chinook salmon estimates after 1981 are based solely on salmon entering the hatchery during the month of September. After 1981, available annual adult in-channel escapement estimates provided by DWR (pers. com., B. Cavallo, 2002) reflect both spring-run Chinook salmon and fall-run Chinook salmon spawning within the Feather River. In order to statistically compare a consistent set of annual escapement data to the available set of flow records during the August through December period, this analysis combined the adult spring-run Chinook salmon and fall-run Chinook salmon in-channel escapement estimates for all years (1967 through 2001). Both the spring- and fall-run hatchery returns were added to the in-channel escapement estimate of Chinook salmon to arrive at the total adult annual escapement estimate used in this analysis.

- Steelhead. No data is available estimating the number of adult steelhead in-channel escapement for the reasons described above under the "Background" section of this report. Because there is no quantitative information available to describe the number of in-channel adult steelhead spawners, it is not possible to assess whether the adult steelhead returns to the Feather River Hatchery are representative of the total number of adult steelhead immigrating in the Feather River. Nonetheless, adult steelhead have returned to the Feather River Fish Hatchery every year since the initiation of hatchery operations, regardless of extant flows. Reported minimum depth of water required for steelhead passage is approximately seven inches (DWR et al. 2002). Depth is usually not a factor preventing access to spawning areas in the Feather River because migration normally occurs during high outflow months. Given their superior leaping and jumping ability in comparison to Chinook salmon (DWR et al. 2002), steelhead are less likely than Chinook salmon to be impacted by physical flow-related passage impediments. Due to the lack of adult in-channel escapement data for steelhead, which results in an incomplete representation of the total steelhead immigrant population, and the fact that steelhead have returned to the hatchery every year and have superior leaping ability compared to Chinook salmon, no specific analysis was conducted investigating the relationship between adult steelhead escapement and flow.

One of the difficulties in investigating the relationship between flow and adult spawner escapement is comparing flow, which varies daily, to one escapement value, which represents the total immigrant population for the spawning season. Ideally, in order to make the data comparable, one metric representing flow would be compared to one metric representing escapement. However, escapement estimates obtained through carcass surveys contain data collected only from October through December, with the addition of September in 2000 and 2001. Although weekly escapement estimates are now generated by DWR, they have only been generated for the last two years. Prior to 2000, escapement is reported as one number representing adult spawning escapement for the entire spawning season. In addition, there is no program to enumerate immigrating salmonids during the immigration period. In other words, there is no June, July, or August immigration data to correlate with June, July, or August flows and clearly there is no escapement data during this time period because spawning has yet to occur. Therefore, in order to use a consistent metric obtained over a long enough time period to provide a meaningful basis of comparison with respect to flow, annual escapement estimates were utilized in the analyses. Given the lack of temporal resolution of the escapement estimates, annual escapement estimates were compared to one numerical estimate of flow over a five month period (average flow over the August through December period) to allow the identification of any gross trends that may be evident. A detailed description of the analytical procedures utilized in the analyses is provided below.

4.1 Acquisition of Salmonid Escapement Data, Flow Data, and Water Year Records

Salmonid Escapement Data. The available series of annual adult fall-run Chinook salmon and spring-run Chinook salmon in-channel escapement estimates (1953 through 2001), fall-run Chinook salmon and spring-run Chinook salmon hatchery counts (1967 through 2001), and steelhead hatchery counts (1967 through 2001) were obtained from the DWR Environmental Services Office on November 26, 2002. The Feather River Fish Hatchery formally began operation in 1967, therefore no reliable hatchery counts are available prior to this date.

Flow Data. The average daily flow records recorded at several U.S. Geological Service (USGS) gaging stations on the Feather River within the study area and on the Yuba River near its confluence with the Feather River were collected from the USGS surface-water data portal (*http://waterdata.usgs.gov/nwis/discharge*) and the DWR California Data Exchange Center website (*http://cdec.water.ca.gov/*) for all years with corresponding adult in-channel escapement estimates and hatchery counts (1967 through 2001). Average daily flow records were obtained for the August 1 through December 31 period from the following gaging stations (**Table 2**):

Table 2. Streamflow gaging stations and availability of daily flow data.

River	Source-Identifier	Station Name	Location	Beginning Date	Ending Date
Feather	USGS-11407150	Near Gridley	39º22'00"; 121º38'46"	10-1-64	9-30-98
Feather	CDEC-GRL	Near Gridley	39.367º; 121.646º	1-1-93	present
Feather	USGS-11407700	At Yuba City	39º08'20"; 121º36'17"	10-1-64	9-30-84
Feather	USGS-11421700	Below Shanghai Bend near Olivehurst	39º04'44"; 121º36'08"	10-1-69	9-30-80
Feather	USGS-11421701	At Shanghai Bend near Olivehurst	39º04'44"; 121º36'08"	10-1-76	9-30-84
Yuba	USGS-11421000	Near Marysville	39º10'33" 121º31'26"	10-1-43	9-30-01

Data limitations resulted in the inability of some periods or locations to be included in the analysis. For example, daily flow data is only available through 1984 on the Feather River at Yuba City (USGS-11407700) and at Shanghai Bend (USGS-11421701). In addition, daily flow data was combined at nearby locations to provide a continuous set of daily flow records for the August 1 through December 31 time period analyzed. Specifically, daily flow records near Gridley utilized in the analysis is a combination of daily flows from USGS gaging station 11407150 from August 1, 1967 through December 31, 1997, and daily flows from CDEC gaging station GRL from August 1, 1998 through December 31, 2001. In addition, daily flow records below/at Shanghai Bend utilized in the analysis is a combination of daily flows from USGS gaging station 11421700 (Below Shanghai Bend near Olivehurst) from August 1, 1969 through December 31, 1979, and daily flows from USGS gaging station 11421701 (At Shanghai Bend near Olivehurst) from August 1, 1980 through September 30, 1984. Daily flow data is not available for the August 1 through December 31 time period for 1967 or 1968 at this location. Because of the availability of flow data, the period of record near Gridley contains 35 years (1967 through 2001), the period of record at Yuba City contains 18 years (1967 through 1984), and the period of record below/at Shanghai Bend contains 16 years (1969 through 1984).

Water Year Records. Water year hydrologic classification indices were obtained from DWR to identify which water years during the study period were classified as "dry," "critical," or "below normal" and which years were classified as "wet" or "above normal." This data was required to provide an analysis using DWR hydrologic classifications as the defining criteria for segregating the escapement data into two series, dryer years (years designated as "dry, "critical," or "below normal"), and wetter years (years designated as "wet" or "above normal").

4.2 Comparison of Total Chinook Salmon Escapement to Average Flows

The following analyses were completed by comparing the total adult Chinook salmon escapement estimates to average daily flow data using both graphical and statistical approaches. A linear regression approach was utilized to evaluate potential relationships between the total Chinook salmon escapement estimate and various flow rate variables based on a defined regulatory or flow level threshold. A summary table is provided for each linear regression analysis completed, indicating the location where the analysis was conducted, the significance level (*P* value), and the coefficient of determination (r^2 value). Graphical representations of each linear regression are located in Appendix A.

For each year from 1967 to 2001, the annual in-channel adult fall-run Chinook salmon and spring-run Chinook salmon escapement estimate and the number of adults returning to the Feather River Fish Hatchery were summed to arrive at the total Chinook salmon escapement estimate. The daily flows from August 1 through December 31 were averaged for each year to arrive at an average flow for the August through December period. For each year, the total Chinook salmon escapement estimate was then graphically compared to the average flow over the August through December period to identify any potentially obvious trend or relationship between the years with the lowest levels of escapement and those years with lower average flows.

4.2.1 Relationship Between Total Chinook Salmon Escapement and Average Flows

For each year from 1967 to 2001, a linear regression approach was used to evaluate the potential relationships between: (1) the total Chinook salmon escapement estimate (dependent variable); and (2) the average flows on the Feather River downstream of the Thermalito Afterbay Outlet during the months of upstream adult migration (August through December) (independent variable). The linear regression analysis was completed at each USGS gaging station location on the Feather River where flow data was obtained (e.g., Feather River at Gridley; Feather River at Yuba City; and Feather River below/at Shanghai Bend). This analysis was completed to identify whether a significant statistical relationship exists between escapement and average flows on the Feather River downstream of the Thermalito Afterbay Outlet.

4.2.2 Relationship Between Total Chinook Salmon Escapement and Quartile Flows

For each year from 1967 to 2001, a linear regression approach was used to evaluate the potential relationships between: (1) the total Chinook salmon escapement estimate (dependent variable); and (2) the 25th, 50th, and 75th percentile (quartile) flows during the months of upstream adult migration (August through December) on the Feather River downstream of the Thermalito Afterbay Outlet (independent variable). The 25th, 50th, and 75th percentile (quartile) flows were calculated for each month of the August through December period and then averaged to arrive at the average August through December quartile flow. The average August through December 25th, 50th, and 75th percentile (quartile) flows were then regressed against the total Chinook salmon escapement estimate for each year. The linear regression analysis was completed at each USGS gaging station location on the Feather River where flow data was obtained (e.g., Feather River at Gridley; Feather River at Yuba City; and Feather River below/at Shanghai Bend). This analysis was completed to identify whether a significant statistical relationships exists between escapement and the 25th, 50th, and 75th percentile flows on the Feather River downstream of the Thermalito Afterbay Outlet.

4.2.3 Relationship Between Total Chinook Salmon Escapement and Number of Days with Flow Less Than 1,700 cfs

For each year from 1967 to 2001, a linear regression approach was used to evaluate the potential relationships between: (1) the total Chinook salmon escapement estimate (dependent variable); and (2) the number of days when daily flows during the months of adult upstream migration (August through December) were lower than 1,700 cfs on the Feather River downstream of the Thermalito Afterbay Outlet (independent variable). The linear regression analysis was completed at each USGS gaging station location on the Feather River where flow data was obtained (e.g., Feather River at Gridley; Feather River at Yuba City; and Feather River below/at Shanghai Bend). Seventeen hundred cubic feet per second (cfs) was chosen as the regulatory basis of comparison because it is the minimum required in-stream flow (during years with greater than 55 percent of normal run-off) for the Feather River below the Thermalito Afterbay Outlet, as established by the August 1983 agreement between DWR and DFG (Table 1). Although Table 1 illustrates that the minimum instream flow requirement may be as low as 1,200 cfs or 1,000 cfs depending upon the percentage of normal runoff at Oroville, there were so few occurrences when daily flow was less than 1,200 cfs or 1,000 cfs over the period of record, as compared to occurrences when daily flow was less than 1,700 cfs (**Table 3**), that 1,700 cfs was chosen as the regulatory basis of comparison.

Table 3. Occurrences of daily flows less than 1,700 cfs, 1,200 cfs, and 1,000 cfs.

Location	# of Days in Period of Record	# of Days < 1,700 cfs	# of Days < 1,200 cfs	# of Days < 1,000 cfs
Near Gridley	5355	1536	836	524
At Yuba City	2754	620	282	132
Below/At Shanghai Bend	2448	166	89	23

4.2.4 Relationship Between Total Chinook Salmon Escapement and Peak Flows

For each year from 1967 to 2001, a linear regression approach was used to evaluate the potential relationships between: (1) the total Chinook salmon escapement estimate (dependent variable); and (2) the average maximum flows for those years having less than 25th percentile maximum flows during the months of upstream adult migration (August through December) on the Feather River downstream of the Thermalito Afterbay Outlet (independent variable). The maximum flow for each month of the August through December period was averaged to arrive at an annual maximum flow. The 25th percentile of the maximum flows for the period of record at each location was calculated, and those years with average maximum flows less than the 25th percentile were then regressed against the total Chinook salmon escapement estimate. The linear regression analysis was completed at each USGS gaging station location on the Feather River where flow data was obtained (e.g., Feather River at Gridley; Feather River at Yuba City; and Feather River below/at Shanghai Bend). This analysis was completed to determine if lower maximum flows (or a lack of peak flows) are related to or influence escapement.

4.3 COMPARISON OF TWO SERIES OF CHINOOK SALMON ESCAPEMENT ESTIMATES

The following analyses were completed by comparing two series of adult Chinook salmon escapement estimates. The total escapement estimate was separated and grouped based on a defined regulatory or flow level threshold. In each case, the mean of the first series was compared to the mean of the second series. The two series were compared using an ANOVA approach (a one-tailed t-Test; $\alpha = 0.05$) to determine whether the mean escapement of the first series was statistically lower than the mean escapement of the second, complementary series. In order to conduct the t-Test to compare the means, the variances were tested to determine whether the t-Test would be conducted assuming equal variance or unequal variance. To this end, a two sample F-Test was performed to determine whether or not the variances for the two series can be considered statistically different ($\alpha = 0.05$). Based upon the results of the F-Test, the appropriate t-Test (assuming equal variance or assuming unequal variance) was conducted.

4.3.1 Comparison of Annual Escapement Estimates Based on Minimum Flow Requirements

The total Chinook salmon escapement estimate was compared for two groups of years over the period of record (1967-2001). The two groups of years were those in which the average flow during the August through December period was lower than 1,700 cfs and those in which the average flow during the August through December period was greater than or equal to 1,700 cfs. The years were grouped using flow data from all three USGS gaging station location on the Feather River where flow data was obtained (e.g., Feather River at Gridley; Feather River at

Yuba City; and Feather River below/at Shanghai Bend). The first series included those years when the average flow during the August through December period at any of the three locations was lower than 1,700 cfs. The second series included those years when the average August through December flows at any of the three locations were greater than or equal to 1,700 cfs. As described above, 1,700 cfs was used to segregate the two series since it is the minimum required in-stream flow (during years with greater than 55 percent of normal run-off) for the Feather River below the Thermalito Afterbay Outlet, as established by the August 1983 agreement between DWR and DFG. Table 1 illustrates that the minimum instream flow requirement may be as low as 1,200 cfs or 1,000 cfs, depending upon the percentage of normal runoff at Oroville. However, there were so few occurrences of average August through December flows of less than 1,200 cfs over the period of record (two of 35 years near Gridley, two of 18 years at Yuba City, and 0 of 16 years below/at Shanghai Bend), and so few occurrences of average August through December flows of less than 1,000 cfs over the period of record (one of 35 years near Gridley, 0 of 18 years at Yuba City, and 0 of 16 years below/at Shanghai Bend), that 1,700 cfs was chosen as the flow used to segregate the two series.

Subsequent to the above analysis, an additional analysis was completed in which the first series included those years when any monthly average flow at any of the three gaging stations during the August through December period was lower than 1,700 cfs. This included those years when the average flow at any of the three gaging stations during only one month of the August through December period was lower than 1,700 cfs. The second series included those years when none of the monthly average flows during the August through December period were lower than 1,700 cfs. The t-Test was conducted to compare the total Chinook salmon escapement estimates of each of these two groups according to the methodology detailed above in the "Comparison of Two Series of Chinook Salmon Escapement Estimates" section of this report.

4.3.2 Comparison of Annual Escapement Estimates Based on Water Year Type

The total Chinook salmon escapement estimate was compared for two groups of years over the period of record (1967-2001). The two groups of years were those in which the water year was classified as a "drier year" (those occurring in years classified by DWR as "dry," "critical," or "below normal" years) and years in which the water year was classified as a "wetter year" (those occurring in years classified by DWR as "wet" or "above normal" years). The years were grouped using the water year type classification currently utilized by DWR. The total Chinook salmon escapement estimate was separated into two series of abundance estimates. The first series included those occurring in years classified by DWR as "dry," "critical," or "below normal" years. The second series included those occurring in years classified by DWR as "wet" or "above normal" years. The t-Test was conducted to compare total Chinook salmon escapement estimates of these two groups according to the methodology detailed above in the "Comparison of Two Series of Chinook Salmon Escapement Estimates" section of this report.

4.3.3 Comparison of Annual Escapement Estimates Based on Average Flows

The total Chinook salmon escapement estimate was compared for two groups of years over the period of record (1967-2001). The two groups of years were those in which there was relatively low flow in the Feather River (noted as "lower flow years") and years in which there was higher flow in the Feather River (noted as "higher flow years"). The years were grouped using flow data from the USGS gaging station location on the Feather River near Gridley. Data from other gaging stations (Feather River at Yuba City and Feather River below/at Shanghai Bend) was not used because of the relatively short period of available flow data (16 to 18 years) at these locations in comparison to the relatively long period of available flow data at the Feather River near Gridley station (35 years). The total Chinook salmon escapement estimate was separated into two series of abundance estimates. The first series included those years described as "lower flow years" and the second series included those years described as "higher flow years." The designation of "lower flow year" versus "higher flow year" was arrived at by considering three separate measures of flow: (1) average flow for each year over the August through December period; (2) average 75th percentile flow for each year over the August through December period; and (3) average 50th percentile flow for each year over the August through December period. Three measures were chosen instead of one in order to more accurately characterize which years were generally years of lower flow. For each measurement of flow considered, a list of the nine years (25 percent of the total years available near Gridley) having the lowest measurement of flow was constructed. The lists of years for all three measurements of flow were compared and in all cases the following years were in the list of nine with the lowest representation of flow: 1967, 1968, 1976, 1977, 1987, 1991, 1992, and 2001. 1980 was the ninth year when both average flow and average 75th percentile flow was used to represent flow, while 1988 was the ninth year when average 50th percentile flow was used to represent flow. Because 1980 was the ninth year in two of the three representations of flow, 1980 was included in the list of nine "lower flow years." The remaining 26 years were included in the second series of years, noted as "higher flow years." The list of ten lowest flow years was identical regardless of the metric used to represent flow. A t-Test was conducted to compare total Chinook salmon escapement estimates in each of these two groups according to the methodology detailed above in the "Comparison of Two Series of Chinook Salmon Escapement Estimates" section of this report.

4.3.4 Comparison of Annual Escapement Estimates Based on Peak Flows

The total Chinook salmon escapement estimate was compared for two groups of years over the period of record (1967-2001). The two groups of years were those in which the average peak (maximum) flow was relatively low (noted as "lower peak flow years") and those years in which there was higher average peak flow in the Feather River (noted as "higher peak flow years"). The years were grouped using flow data from the USGS gaging station location on the Feather River near Gridley. Data from other gaging stations (Feather River at Yuba City and Feather River below/at Shanghai Bend) was not used because of the relatively short period of available flow data (16 to 18 years) at these locations in comparison to the relatively long period of available flow data at the Feather River near Gridley station (35 years). The total Chinook salmon escapement estimate was separated into two series of abundance estimates. The first series included those years described as "lower peak flow years" and the second series included those years described as "higher peak flow years." "Lower peak flow years" were characterized as those nine years (25 percent of the total 35 years available near Gridley) having the lowest measurement of average peak (maximum) flow. "Higher peak flow years" were characterized as those remaining 26 years (75 percent of the total 35 years available near Gridley) having the highest measurement of average peak (maximum) flow. A t-Test was conducted to compare total Chinook salmon escapement estimates in each of these two groups according to the methodology detailed above in "Comparison of Two Series of Chinook Salmon Escapement Estimates."

5.0 RESULTS AND DISCUSSION

5.1 SALMONID ESCAPEMENT ESTIMATES

Based on escapement estimates provided by DWR (**Table 4**), other than the first two years of escapement estimates (1967 and 1968), the years 1979, 1983, and 1990 were identified as the years with the lowest total escapement estimate. This estimate is a combined in-channel and hatchery escapement estimate for adult fall-run and spring-run Chinook salmon. The total escapement estimates for 1979, 1983, and 1990 are 32,555, 32,234, and 32,431, respectively.

Table 4. Feather River Chinook salmon escapement estimates.

Year	Fall-Run Chinook Escapement	Spring-Run Chinook Escapement	Total Annual Escapement
1967	11956	246	12202
1968	18144	416	18560
1969	60578	412	60990
1970	61525	435	61960
1971	47041	984	48025
1972	46835	556	47391
1973	73577	405	73982
1974	65946	398	66344
1975	43000	1391	44391
1976	62000	1413	63413
1977	46452	321	46773
1978	37759	402	38161
1979	32505	50	32555
1980	35295	522	35817
1981	53020	969	53989
1982	55519	1910	57429
1983	30522	1712	32234
1984	50842	1562	52404
1985	56003	1632	57635
1986	55345	1433	56778
1987	69082	1213	70295
1988	60696	6833	67529
1989	37564	5078	42642
1990	31125	1306	32431
1991	38160	4303	42463
1992	40542	1497	42039
1993	40694	4885	45579
1994	51732	3486	55218
1995	71800	5414	77214
1996	64600	6381	70981
1997	70500	3653	74153
1998	60800	6746	67546
1999	48300	3731	52031
2000	144600	3675	148275
2001	192895	4132	197027

5.2 COMPARISON OF TOTAL CHINOOK SALMON ESCAPEMENT TO AVERAGE FLOWS

The series of total Chinook salmon escapement estimates were compared graphically to average flow during the August through December period. As shown in **Figure 2**, there are instances (i.e., 1983) in which the total escapement estimate is relatively low (32,234), but the average flow at each gaging station location utilized is relatively high (15,001 cfs below/at Shanghai Bend). Although 1983 was identified as the year with the lowest total escapement estimate, it also had the highest average flow in the August through December period at each location. There are also several instances (i.e., 1976, 1977, 1985, 1987, 1988, 2000, and 2001) where the total escapement estimate is approximately average or relatively high (ranging from 46,773 to 197,027 for these time periods), although the average flow at each location is relatively low (1,027 cfs in 1977 near Gridley). Figure 2 illustrates higher escapement estimates in 2000 and 2001, which may potentially result from the greater effort and detailed sampling protocol that was employed during the field surveys conducted in 2000 and 2001 (see the above "Background" section of this report for additional discussion of 2000 and 2001 survey methods).

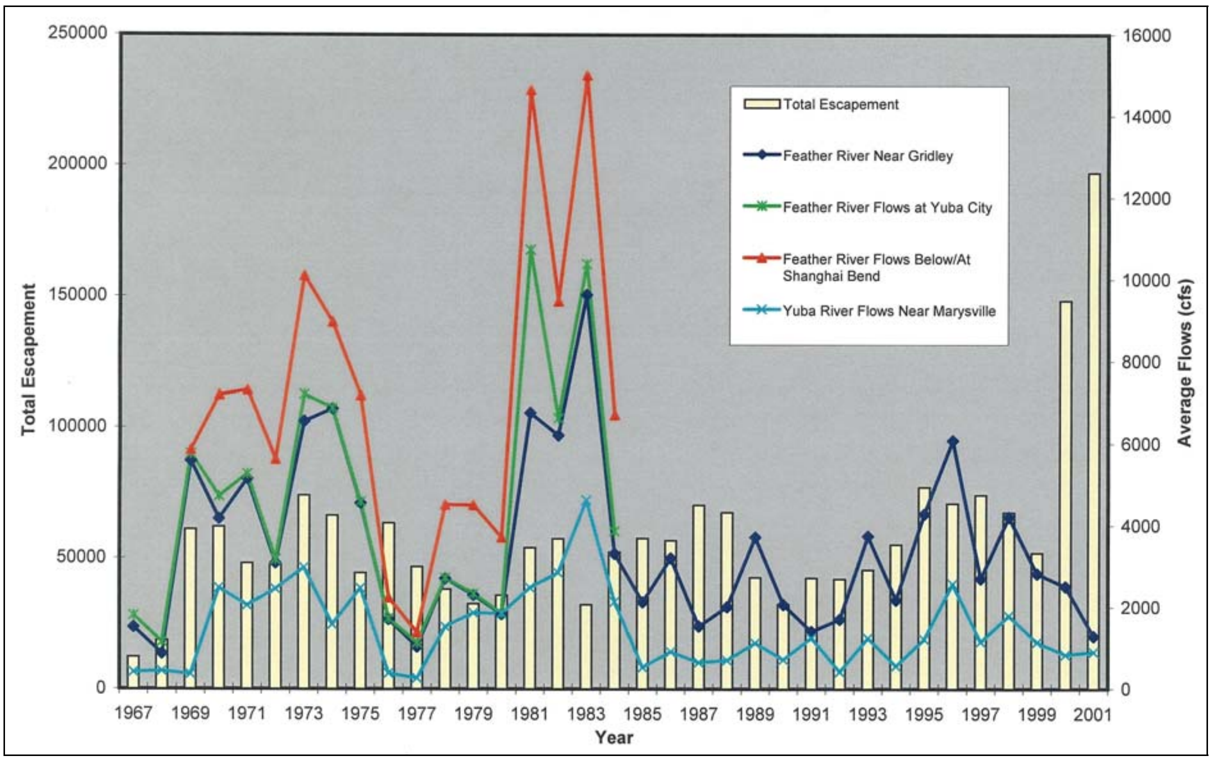

Figure 2. Total escapement vs. average (August-December) flows.

5.2.1 Relationship Between Total Chinook Salmon Escapement and Average Flows

A linear regression approach was used to evaluate the potential relationships between: (1) the total Chinook salmon escapement estimate; and (2) the average flows during the months of upstream adult migration (August through December) on the Feather River downstream of the Thermalito Afterbay Outlet. The results of the linear regression analysis (**Table 5**) showed that *P* (defined as the probability that the results could be obtained by chance alone) is not less than 0.05 at any study locations on the Feather River, indicating that there is no significant relationship between escapement and average flows at these locations. For a graphical representation of this analysis, please refer to Figures A-1 through A-3 in Appendix A.

Table 5. Linear regression results summary - total escapement vs. average flows.

Location	*P*	Significant relationship (P<0.05)?	r^2
Near Gridley	0.79	No	0.00
At Yuba City	0.09	No	0.16
Below/At Shanghai Bend	0.70	No	0.01

5.2.2 Relationship Between Total Chinook Salmon Escapement and Quartile Flows

A linear regression approach was used to evaluate the potential relationships between: (1) the total Chinook salmon escapement estimates, and (2) the 25th, 50th, and 75th percentile flows during the months of upstream adult migration (August through December) on the Feather River downstream of the Thermalito Afterbay Outlet. The results of the linear regression analyses varied based on location and flow rates (**Table 6**). In each case, if *P* is less than 0.05, there is a significant relationship between total escapement and flow, but if *P* is greater than 0.05, there is no significant relationship between total escapement and flow. The proportion of the variation in escapement that is explained by flow varies at each location and for each percentile studied. For a graphical representation of this analysis, please refer to Figures A-7 through A-15 in Appendix A.

Table 6. Linear regression results summary - total escapement vs. average quartile flows.

Location	Percentile	*P*	Significant relationship (P<0.05)?	r^2
Near Gridley	25th	0.80	No	0.00
	50th	0.91	No	0.00
	75th	0.78	No	0.00
At Yuba City	25th	0.04	Yes	0.24
	50th	0.01	Yes	0.32
	75th	0.12	No	0.14
Below/At Shanghai Bend	25th	0.67	No	0.01
	50th	0.28	No	0.08
	75th	0.60	No	0.02

As illustrated in Table 6, the only location in which a significant relationship between flow and escapement was at Yuba City. One reason the analysis may show a significant relationship using flow data obtained at Yuba City and not at other locations could be that the composition of years included in the analysis differs from flow gage to flow gage. As described above under the "Flow Data" section of this report, flow records at Yuba City are available from 1967 through 1984, while those at Shanghai Bench are available from 1969 through 1984, and those near Gridley are available from 1967 to the present. Because the composition of years in which the analysis was conducted differs at each site, it is possible that the analysis results will differ. Additionally, average flow during the August through December period will vary from site to site. However, Figure 2 illustrates that even though average flow during the August through December period varies from site to site, average flow during the August thought December period follows similar trends at all three sites. When the period of record is expanded to include all available flow and total Chinook salmon escapement estimates (as available near Gridley), the relationship between flow and total Chinook salmon escapement estimates is not statistically significant, and the coefficient of determination (r^2) is so low that flow accounts for none of the variation in escapement. Therefore, the relationship suggested at Yuba City may be an artifact of the particular composition of years for which flow data is available at Yuba City. Because no significant relationship between flow and escapement was found using any quartile flow at either Gridley or Shanghai Bench, and because of the reasons discussed above regarding the results obtained utilizing flow at Yuba City, no strong, consistent relationship between flow and escapement was identified using the 25th, 50th, or 75th percentile flows as the metric representing flow.

5.2.3 Relationship Between Total Chinook Salmon Escapement and Number of Days with Flow Less Than 1,700 cfs

A linear regression approach was used to evaluate the potential relationships between: (1) the total Chinook salmon escapement estimate; and (2) the number of days when daily flows during the months of upstream adult migration (August through December) were lower than 1,700 cfs on the Feather River downstream of the Thermalito Afterbay Outlet. The results of the linear regression analysis (**Table 7**) showed that P is less than 0.05 ($P = 0.04$) on the Feather River at Yuba City, indicating that there is a significant relationship between total escapement and the number of days with flows less than 1,700 cfs at this location. However, the coefficient of determination (r^2) is low, indicating that only 26 percent of the variation in escapement is explained by flow at Yuba City. As described earlier, the relationship at Yuba City may be an artifact of the particular composition of years for which flow data is available at Yuba City. In addition, because P is greater than 0.05 ($P = 0.65$) on the Feather River near Gridley and below/at Shanghai Bend ($P = 0.94$), there is not a significant relationship between total escapement and the number of days with flow less than 1,700 cfs at these locations. In combination, these results suggest that no strong, consistent relationship exists between flow and escapement using this comparison. For a graphical representation of this analysis, please refer to Figures A-4 through A-6 in Appendix A.

Table 7. Linear regression results summary - total escapement vs. number of days with flow less than 1,700 cfs.

Location	P	Significant relationship (P<0.05)?	r^2
Near Gridley	0.65	No	0.01
At Yuba City	0.04	Yes	0.26
Below/At Shanghai Bend	0.94	No	0.00

5.2.4 Relationship Between Total Chinook Salmon Escapement and Peak Flows

A linear regression approach was used to evaluate the potential relationships between: (1) the total Chinook salmon escapement estimates; and (2) the average maximum flows for those years having less than 25th percentile maximum flows on the Feather River downstream of the Thermalito Afterbay Outlet. At each location, because the significance level (P) was not less than 0.05, the results of the analyses showed no significant relationship between escapement and those years with less than 25th percentile flows (**Table 8**). Variable percentages of the outcomes can be attributed to flow at each location. The results of this analysis suggest that there is no strong, consistent relationship between lower maximum flows (or a lack of peak flows) and total escapement. For a graphical representation of this analysis, please refer to Figures A-16 through A-18 in Appendix A.

Table 8. Linear regression results summary - total escapement vs. 25th percentile maximum average flows.

Location	P	Significant relationship (P<0.05)?	r^2
Near Gridley	0.72	No	0.02
At Yuba City	0.97	No	0.00
Below/At Shanghai Bend	0.36	No	0.41

5.2.5 Conclusions Regarding Comparisons of Total Chinook Salmon Escapement to Average Flows

Using regression analyses, comparisons of the total Chinook salmon escapements to several different measures of flow during the August through December period (average flows, average quartile flows including 25th, 50th, and 75th percentile flows, the number of days under 1,700 cfs, and the average maximum flows for those years having less than 25th percentile maximum flow) were completed. The analyses illustrated that there was no consistent relationship between low flow and escapement estimates that might be suggestive of potential flow-related physical impediments to upstream passage. At two of the three locations where flow data was utilized (near Gridley and below/at Shanghai Bend), none of the analyses comparing flow to escapement illustrated a statistically significant ($P < 0.05$) relationship between flow and escapement. Of the six regressions conducted using flow data from the Yuba City location, three regressions suggested a statistically significant relationship ($P < 0.05$) between flow and escapement, with all three analyses suggesting that the percentage of the variation in escapement that is explained by flow was relatively low (24 to 32 percent). In conclusion, given that no statistically significant relationship between flow and escapement was identified at two of the three locations, and given that for the one location where a statistically significant relationship was found, the coefficient of determination was very small, flow-related physical passage impediments to adult salmonid upstream migration are not apparent in the Feather River.

5.3 Comparison of Two Series of Total Chinook Salmon Escapement Estimates

5.3.1 Comparison of Annual Escapement Estimates Based Minimum Flow Requirements

The analyses to compare the means of the two series described above based on average flow during the August through December period using 1,700 cfs as the defining criteria was completed to identify any consistent temporal pattern among flow and escapement that might be suggestive of potential flow-related physical impediments to upstream passage. The results of the F-Test comparing the variance of the escapement estimates of the two series indicated that because *P* was less than 0.05 (*P* = 0.00), the variances of the two series should be considered statistically different (**Table 9**).

Table 9. F-Test two-sample for variances using 1,700 cfs August through December average as the defining criteria.

	Monthly Flows < 1,700 cfs	Monthly Flows >or = 1,700 cfs
Mean	64553.33	57211.59
Variance	4648482198	481311193.6
Observations	6	29
df	5	28
F	9.66	
P(F<=f) one-tail	1.92E-05	
F Critical one-tail	2.56	

Because the results of the F-Test indicated that the variances of the two escapement series described above are statistically different, the comparison of the means of the two escapement series was completed using a t-Test approach for unequal variances. The results of the t-Test using 1,700 cfs as the defining criteria indicated that because *P* is not less than 0.05 (*P* = 0.40), the difference in means of the two escapement series is not statistically significant (**Table 10**). Therefore, during the period from 1967 through 1998, the average total Chinook salmon escapement during years in which the average flow during the August through December period was less than 1,700 cfs was shown not to be statistically different than the average total Chinook salmon escapement during years in which the average flow during the August through December period was greater than or equal to 1,700 cfs.

Table 10. t-Test: two-sample assuming unequal variances using 1,700 cfs August through December average as the defining criteria.

	Monthly Flows < 1,700 cfs	Month Flows > or = 1,700 cfs
Mean	64553.33	57211.59
Variance	4648482198	481311193.6
Observations	6	29
Hypothesized Mean Difference	0	
df	5	
t Stat	0.26	
P(T<=t) one-tail	0.40	
t Critical one-tail	2.02	
P(T<=t) two-tail	0.81	
t Critical two-tail	2.57	

Subsequent to the above analysis, an additional analysis was completed in which the first series included those years when any monthly average flow was less than 1,700 cfs and the second series included those years when none of the monthly average flows were less than 1,700 cfs. The results of the F-Test comparing the variance of the escapement estimates of these two series indicated that because *P* was less than 0.05 (*P* = 0.00), the variances of the two series should be considered statistically different (**Table 11)**.

Table 11. F-Test two-sample for variances using 1,700 cfs monthly average as the defining criteria.

	Monthly Flows < 1,700 cfs	Monthly Flows >or = 1,700 cfs
Mean	60439.84	56131.19
Variance	1898622215	176709652.3
Observations	19	16
df	18	15
F	10.74	
P(F<=f) one-tail	1.46E-05	
F Critical one-tail	2.35	

Because the results of the F-Test indicated that the variances of the two escapement series described above are statistically different, the comparison of the means of the two escapement series was completed using a t-Test approach for unequal variances. The results of the t-Test using 1,700 cfs as the defining criteria indicated that because *P* is not less than 0.05 ($P = 0.34$), the difference in means of the two escapement series is not statistically significant (**Table 12**). Therefore, during the period from 1967 through 1998, the average total Chinook salmon escapement during years in which monthly flow average was less than 1,700 cfs was shown not to be statistically different than the average total Chinook salmon escapement during years in which monthly flow average was greater than or equal to 1,700 cfs.

Table 12. t-Test: two-sample assuming unequal variances using 1,700 cfs monthly average as the defining criteria.

	Monthly Flows < 1,700 cfs	Month Flows > or = 1,700 cfs
Mean	60439.84	56131.19
Variance	1898622215	176709652.3
Observations	19	16
Hypothesized Mean Difference	0	
df	22	
t Stat	0.41	
P(T<=t) one-tail	0.34	
t Critical one-tail	1.72	
P(T<=t) two-tail	0.69	
t Critical two-tail	2.07	

5.3.2 Comparison of Annual Escapement Estimates Based on DWR Water Year Type

The analyses to compare the means of the two series described above using DWR water year hydrologic classifications as the defining criteria was completed to identify any consistent temporal pattern among low flow and low escapement years that might be suggestive of potential flow-related physical impediments to upstream passage. The results of the F-Test comparing the variance of the escapement estimates of the two series indicated that because *P* was less than 0.05 ($P = 0.04$), the variances of the two series should be considered statistically different (**Table 13**).

Table 13. F-Test two-sample for variance using DWR water year classifications as the defining criteria.

	Dry Years[1]	Wet Years[2]
Mean	57997.33	58824.8
Variance	1675077770	712112262.4
Observations	15	20
df	14	19
F	2.35	
P(F<=f) one-tail	0.04	
F Critical one-tail	2.26	

[1] DWR water year hydrologic classifications of "dry," "critical," or "below normal."
[2] DWR water year hydrologic classifications of "wet' or "above normal."

Because the results of the F-Test indicated that the variances of the two escapement series described above are statistically different, the comparison of the means of the two escapement series was completed using a t-Test approach for unequal variances. The results of the t-Test using DWR water year hydrologic classifications as the defining criteria indicated that because *P* is not less than 0.05 (*P* = 0.47), the difference in means between the two series is not statistically significant (**Table 14**). Therefore, during the period of 1967 through 2001, the average total Chinook salmon escapement during dryer water years (classified by DWR as "dry," "critical," or "below normal") was shown not to be statistically different than the average total Chinook salmon escapement during wetter water years (classified by DWR as "wet" or "above normal").

Table 14. t-Test: two-sample assuming unequal variances using DWR water year classifications as the defining criteria.

	Dry Years[1]	Wet Years[2]
Mean	57997.33	58824.8
Variance	1675077770	712112262.4
Observations	15	20
Hypothesized Mean Difference	0	
Df	23	
t Stat	-0.07	
P(T<=t) one-tail	0.47	
t Critical one-tail	1.71	
P(T<=t) two-tail	0.95	
t Critical two-tail	2.07	

[1] DWR water year hydrologic classifications of "dry," "critical," or "below normal."
[2] DWR water year hydrologic classifications of "wet' or "above normal."

5.3.3 Comparison of Annual Escapement Estimates Based on Average Flows

The analyses to compare the means of the two series of escapement estimates described above grouped into "lower flow years" and "higher flow years" was completed to identify any consistent temporal pattern among low flow and low escapement years that might be suggestive of potential flow-related physical impediments to upstream passage. The results of the F-Test comparing the variance of the escapement estimates of the two series indicated that because *P* was less than 0.05 (*P* = 0.00), the variances of the two series should be considered statistically different (**Table 15**).

Table 15. F-Test two-sample for variance using average flow in "lower flow years" and "higher flow years" as the defining criteria.

	Lower Flow Years	Higher Flow Years
Mean	58732.11	58379.5
Variance	3033925469	508594224.3
Observations	9	26
df	8	25
F	5.97	
P(F<=f) one-tail	0.00	
F Critical one-tail	2.34	

Because the results of the F-Test indicated that the variances of the two escapement series described above are statistically different, the comparison of the means of the two escapement series was completed using a t-Test approach for unequal variances. The results of the t-Test indicated that because *P* is not less than 0.05 (*P* = 0.49), the difference in means between the two series is not statistically significant (**Table 16**). Therefore, during the period of 1967 through 2001, the average total Chinook salmon escapement during "lower flow years" was shown not to be statistically different than the average total Chinook salmon escapement during "higher flow years".

Table 16. t-Test: two-sample assuming unequal variances using average flow in "lower flow years" and "higher flow years" as the defining criteria.

	Lower Flow Years	Higher Flow Years
Mean	58732.11	58379.5
Variance	3033925469	508594224.3
Observations	9	26
Hypothesized Mean Difference	0	
Df	9	
t Stat	0.02	
P(T<=t) one-tail	0.49	
t Critical one-tail	1.83	
P(T<=t) two-tail	0.99	
t Critical two-tail	2.26	

5.3.4 Comparison of Annual Escapement Estimates Based on Peak Flows

The analyses to compare the means of the two series described above as "lower peak flow years" and "higher peak flow years" was completed to identify any consistent temporal pattern among low flow and low escapement years that might be suggestive of potential flow-related physical impediments to upstream passage. The results of the F-Test comparing the variance of the escapement estimates of the two series indicated that because *P* was less than 0.05 (*P* = 0.00), the variances of the two series should be considered statistically different (**Table 17**).

Table 17. F-Test two-sample for variance using maximum flow in "lower peak flow years" and "higher peak flow years" as the defining criteria.

	Lower Peak Flow Years	Higher Peak Flow Years
Mean	59189.44	58221.19
Variance	3040624488	506233071.4
Observations	9	26
df	8	25
F	6.01	
P(F<=f) one-tail	0.00	
F Critical one-tail	2.34	

Because the results of the F-Test indicated that the variances of the two escapement series described above are statistically different, the comparison of the means of the two escapement series was completed using a t-Test approach for unequal variances. The results of the t-Test comparing escapement in "lower peak flow years" to escapement in "higher peak flow years" indicated that because *P* is not less than 0.05 ($P = 0.48$), the difference in means between the two series is not statistically significant (**Table 18**). Therefore, during the period of 1967 through 2001, the average total Chinook salmon escapement during "lower peak flow years" was shown not to be statistically different from the average total Chinook salmon escapement during "higher peak flow years."

Table 18. t-Test: two-sample assuming unequal variances using maximum flow in "lower peak flow years" and "higher peak flow years" as the defining criteria.

	"Lower Peak Flow Years"	"Higher Peak Flow Years"
Mean	59189.44	58221.19
Variance	3040624488	506233071.4
Observations	9	26
Hypothesized Mean Difference	0	
Df	9	
t Stat	0.05	
P(T<=t) one-tail	0.48	
t Critical one-tail	1.83	
P(T<=t) two-tail	0.96	
t Critical two-tail	2.26	

5.3.5 Conclusions Regarding Comparison of Two Series of Total Chinook Salmon Escapement Estimates

Various series of total Chinook salmon escapements were compared using t-Tests to determine if the mean escapement of one series differed from the mean escapement of another series (escapement in years in which average flow over the August through December period was less than 1,700cfs compared to escapement in years in which average flow over the August through December period was greater than or equal to 1,700cfs; escapement in dryer water years [those classified as "dry," "critical," or "below normal"] as compared to escapement in wetter water years [those classified as "wet" or "above normal"]; escapement in "lower flow years" [defined by examining average flow, 75th percentile flow, and 50th percentile flow] as compared to escapement in “higher flow years;” and escapement in “lower peak flow years” as compared to escapement in “higher peak flow years.” These comparisons suggested that the mean escapement for those years with lower flows was not statistically different from the mean escapement for those years with higher flows, and the mean escapement of dryer years was not statistically different from the mean escapement of wetter years, regardless of the method used for defining “lower flow” and “higher flow” years or “dryer” and “wetter” years. In conclusion, various statistical examinations indicate that no statistically significant difference exists between adult Chinook salmon spawning escapement in dryer, lower flow years compared to wetter, higher flow years.

6.0 CONCLUSIONS

The results of the above analytical approaches suggest that there is no consistent temporal pattern among flow and escapement that might be suggestive of potential flow-related physical impediments to upstream passage of adult salmonids. Using regression analyses, comparisons of total Chinook salmon escapement to several different measures of flow illustrated that there was no consistent relationship between low flow and escapement estimates that might be suggestive of potential flow-related physical impediments to upstream passage. At two of the three locations where flow data was utilized (near Gridley and below/at Shanghai Bend), none of the comparisons of flow to escapement illustrated a statistically significant ($P < 0.05$) relationship. Of the six regressions conducted using flow data from the Yuba City location, three regressions suggested a statistically significant relationship ($P < 0.05$), with all three analyses suggesting that the percentage of the variation in escapement that is explained by flow is relatively low (24 to 32 percent). In addition to regression analyses, various series of total Chinook salmon escapements were compared using t-Tests to determine if the mean escapement of one series differed from the mean escapement of another series. The series were constructed using several metrics describing flow and water year type. Results of the t-Test comparisons suggested that the mean escapement for those years with lower flows was not statistically different from the mean escapement for those years with higher flows, and the mean escapement of dryer years was not statistically different from the mean escapement of wetter years, regardless of the method used for defining “lower flow” and “higher flow” years or “dryer” and “wetter” years. In conclusion, various statistical examinations indicate that no statistically significant difference exists between adult Chinook salmon spawning escapement in dryer, lower flow years compared to wetter, higher flow years. Therefore, a detailed evaluation of the relationships between flow and the passage of adult salmonid at Shanghai Bench is not recommended.

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Oroville FERC Relicensing
(Project No. 2100)

INTERIM REPORT
SP-F10, Task 1C

Appendix A
Graphical Representation of Linear Regression Analyses

Evaluation of Flow-Related Physical Impediments in the Feather River Below the Fish Barrier Dam

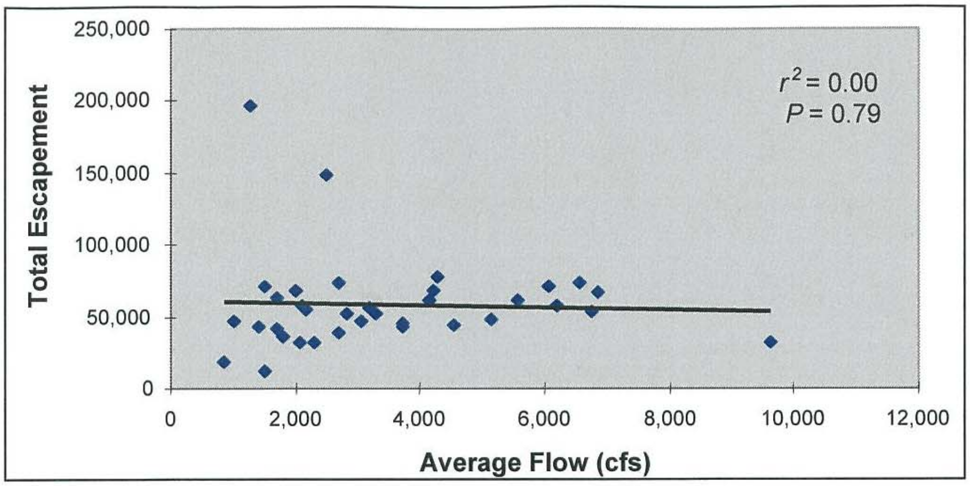

Figure A-1. Total escapement vs. average flow near Gridley.

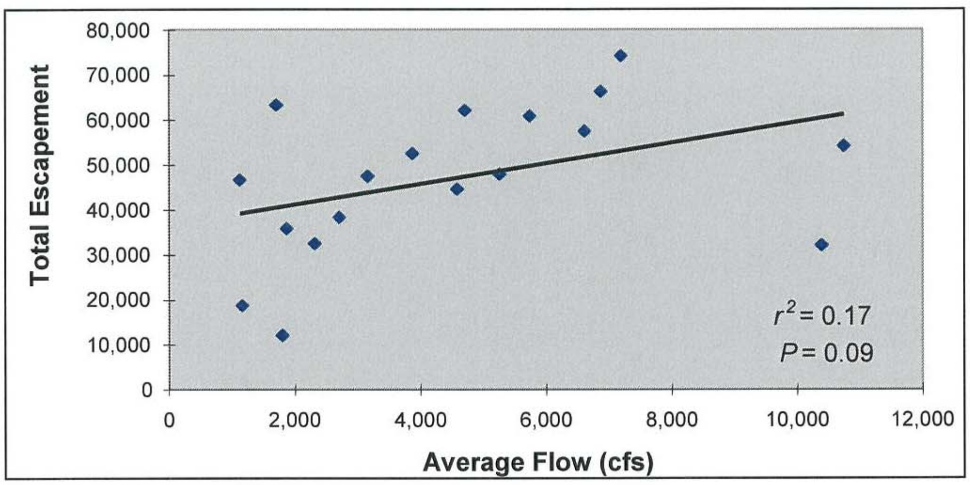

Figure A-2. Total escapement vs. average flows at Yuba City.

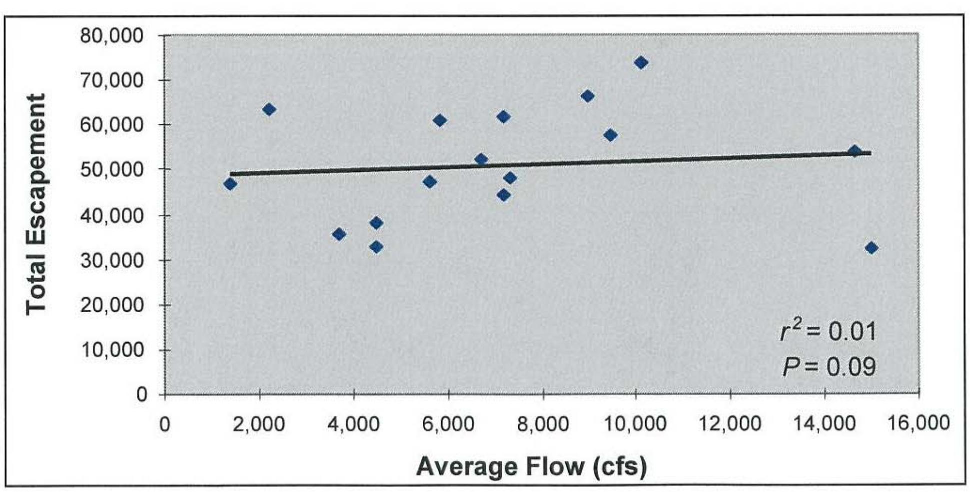

Figure A-3. Total escapement vs. average flows below/at Shanghai Bend.

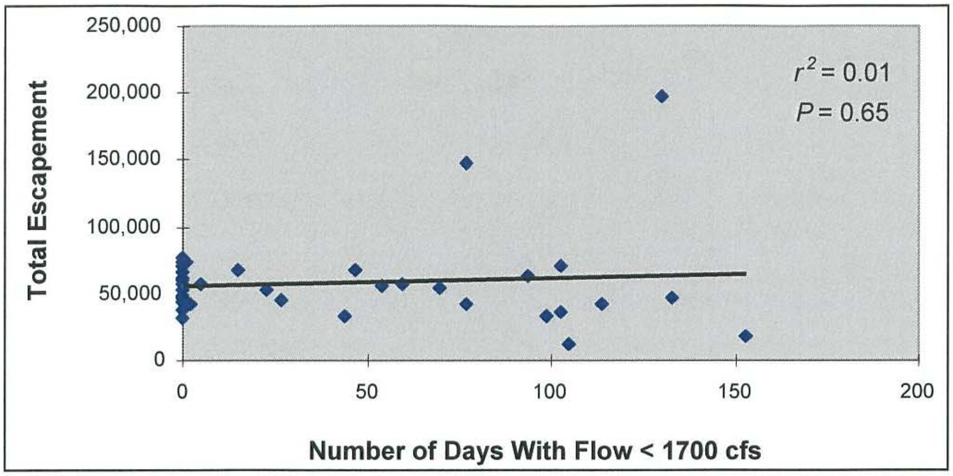

Figure A-4. Total escapement vs. number of days with flow <1,700 cfs near Gridley.

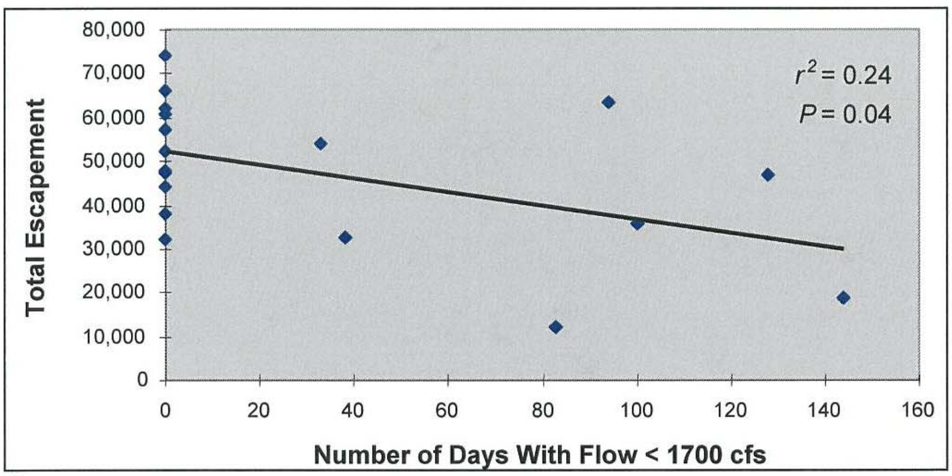

Figure A-5. Total escapement vs. number of days with flow <1,700 cfs at Yuba City.

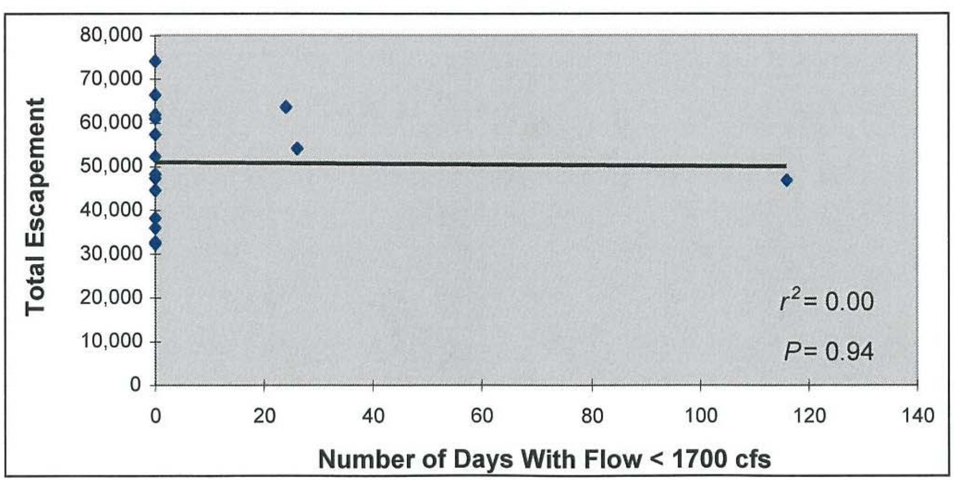

Figure A-6. Total escapement vs. number of days with flow <1,700 cfs below/at Shanghai Bend.

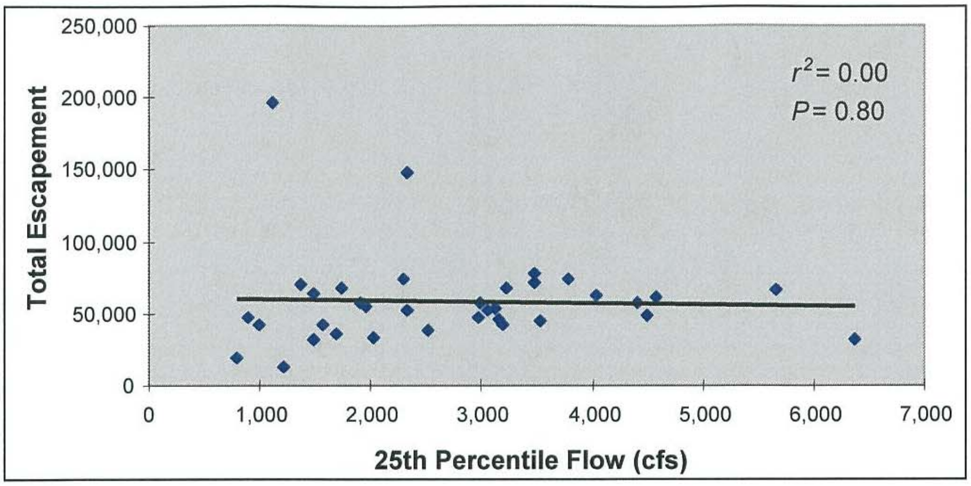

Figure A-7. Total escapement vs. 25th percentile flow near Gridley.

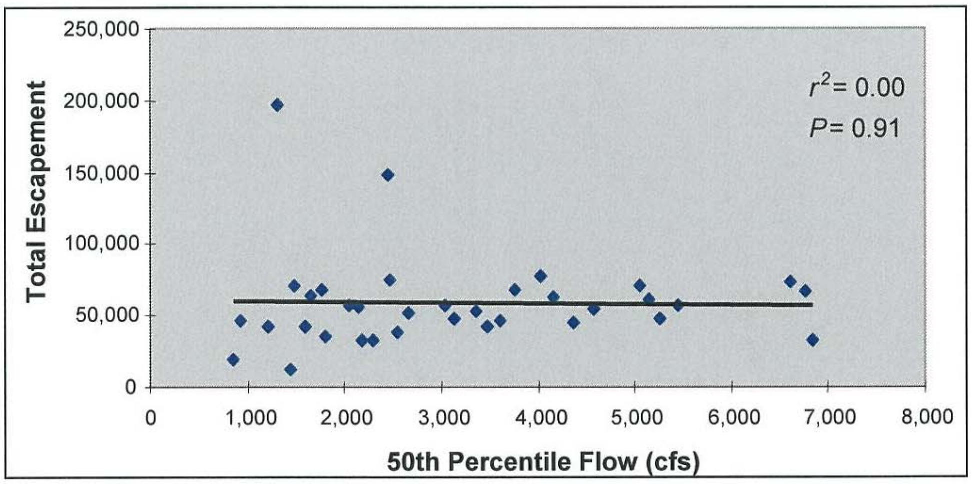

Figure A-8. Total escapement vs. 50th percentile flow near Gridley.

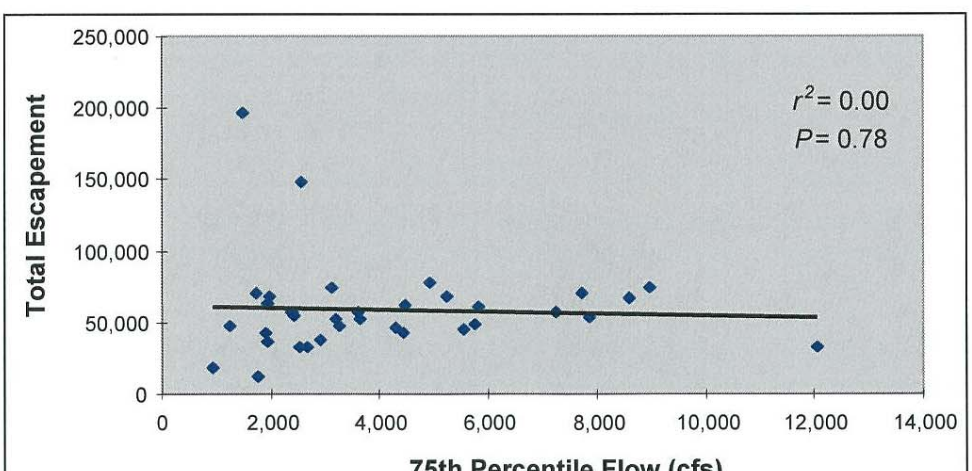

Figure A-9. Total escapement vs. 75th percentile flow near Gridley.

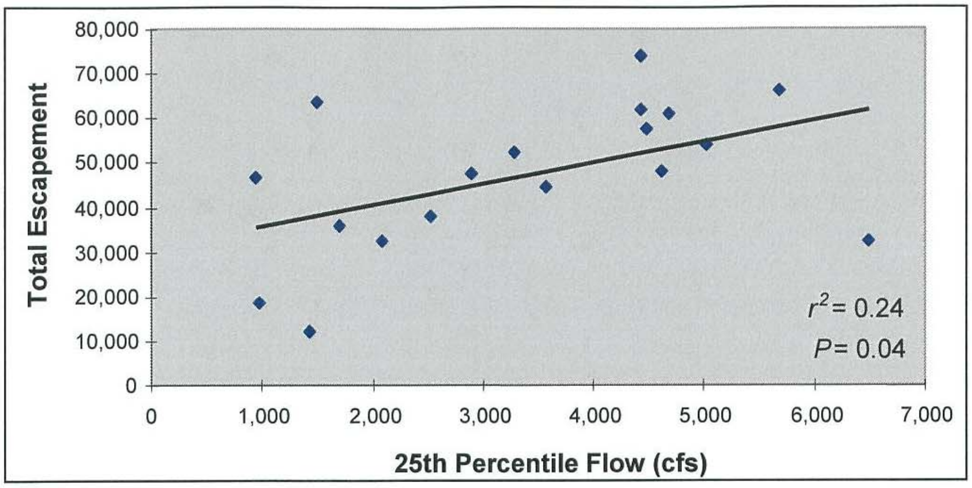

Figure A-10. Total escapement vs. 25th percentile flow at Yuba City.

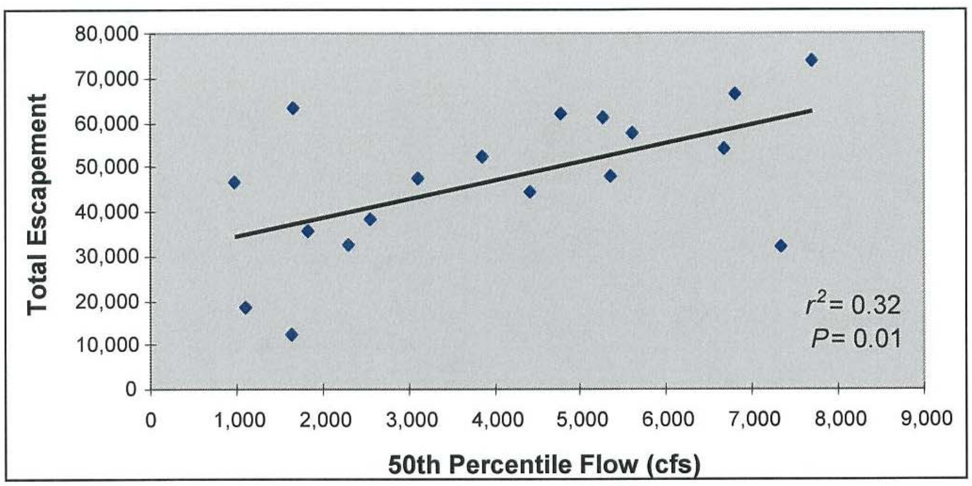

Figure A-11. Total escapement vs. 50th percentile flow at Yuba City.

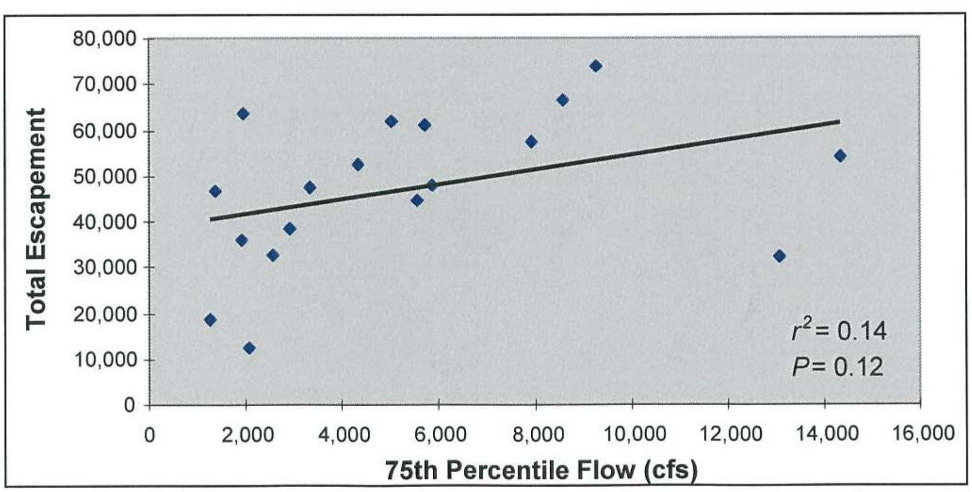

Figure A-12. Total escapement vs. 75th percentile flow at Yuba City.

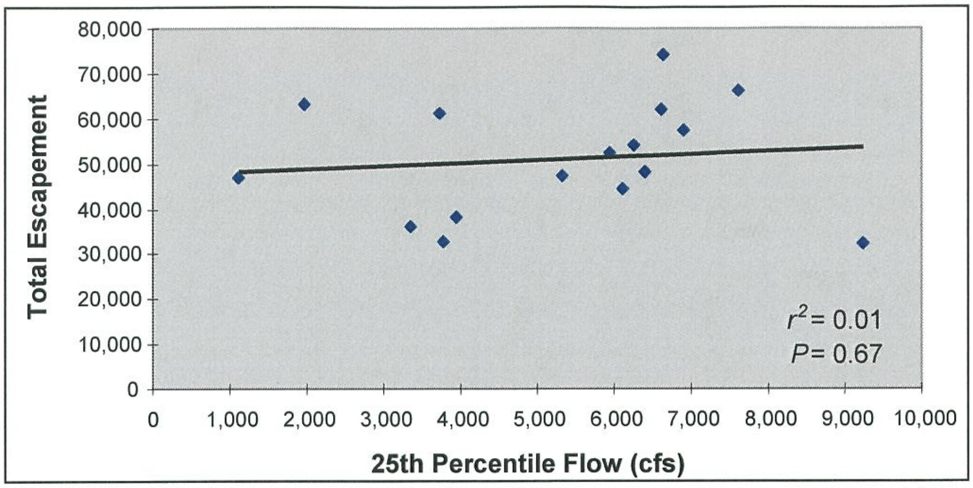

Figure A-13. Total escapement vs. 25th percentile flow below/at Shanghai Bend.

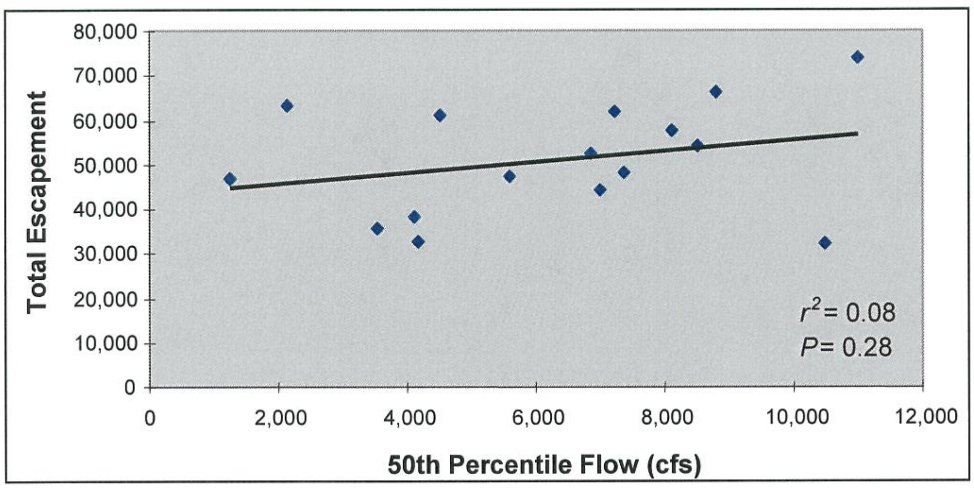

Figure A-14. Total escapement vs. 50th percentile flow below/at Shanghai Bend.

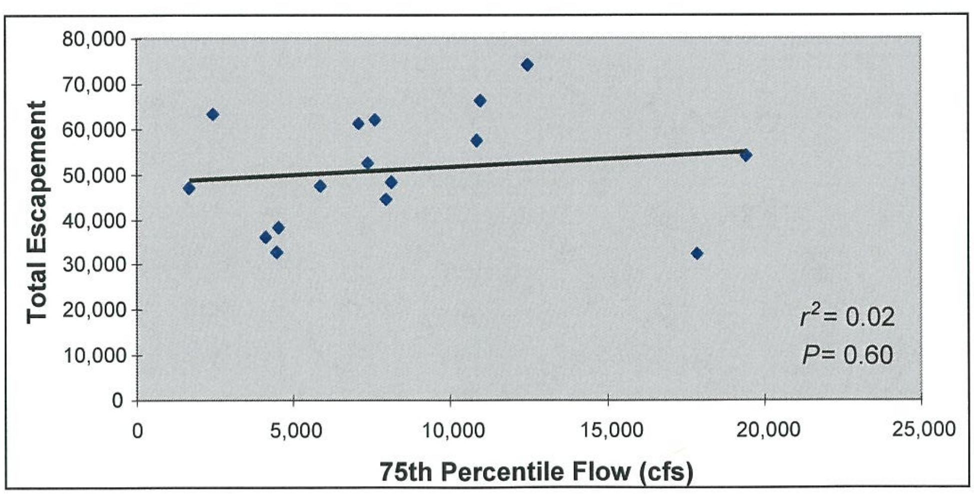

Figure A-15. Total escapement vs. 75th percentile flow below/at Shanghai Bend.

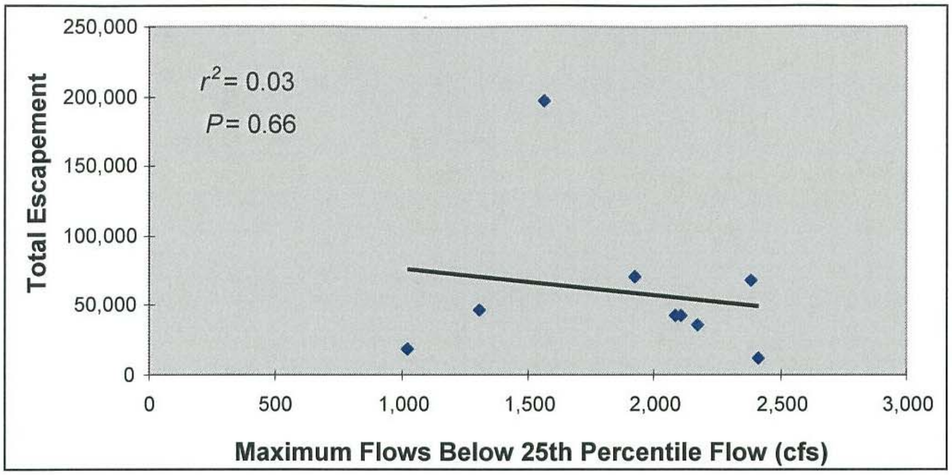

Figure A-16. Total escapement vs. yearly maximum flow below 25[th] percentile near Gridley.

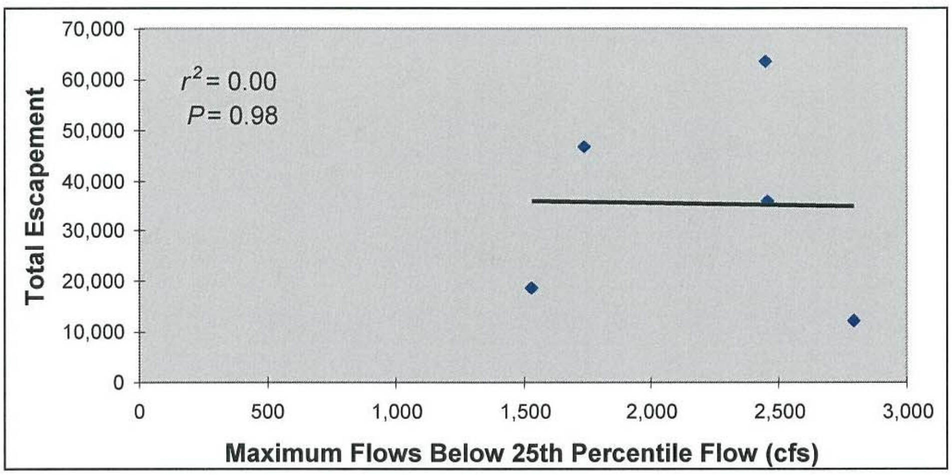

Figure A-17. Total escapement vs. yearly maximum flow below 25th percentile at Yuba City.

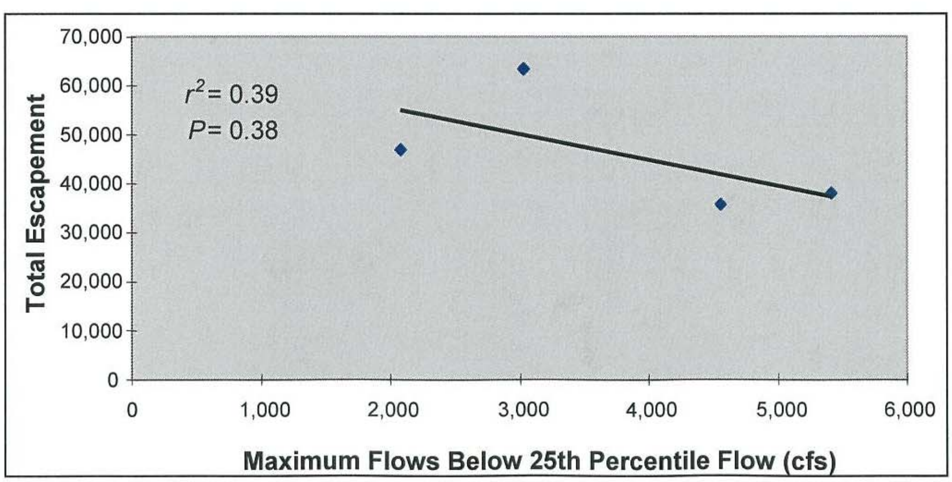

Figure A-18. Total escapement vs. yearly maximum flow below 25th percentile below/at Shanghai Bend.